The small-gap technique
Understanding an ion-shading method for plasma-surface interactions study

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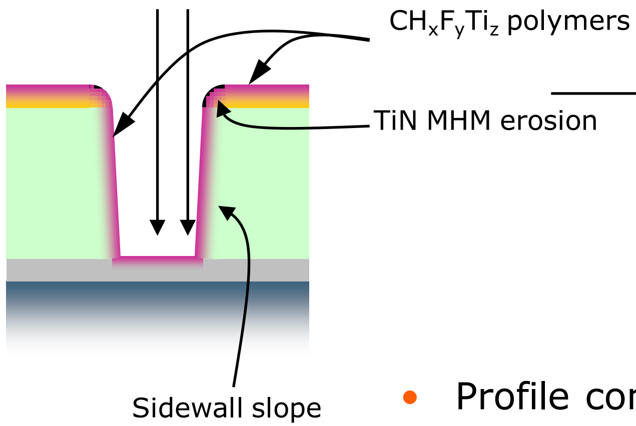
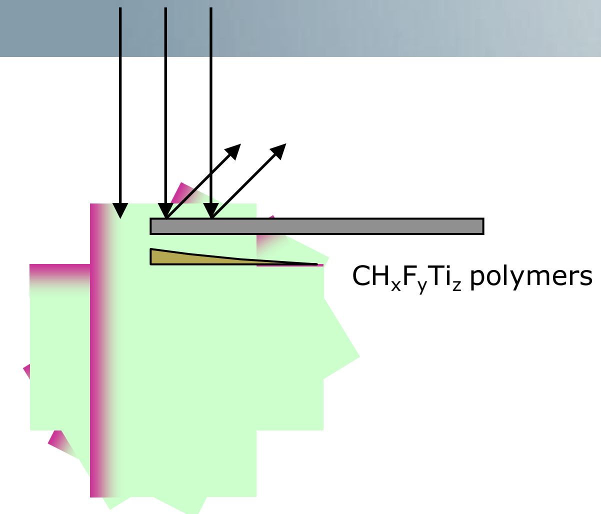
Motivation

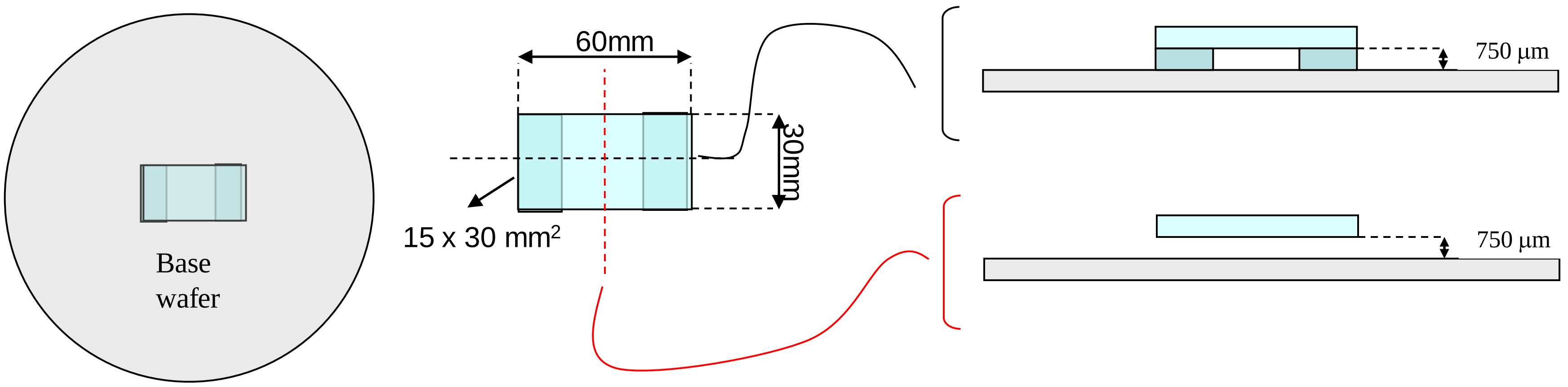
Schematic of a trench into a dielectric

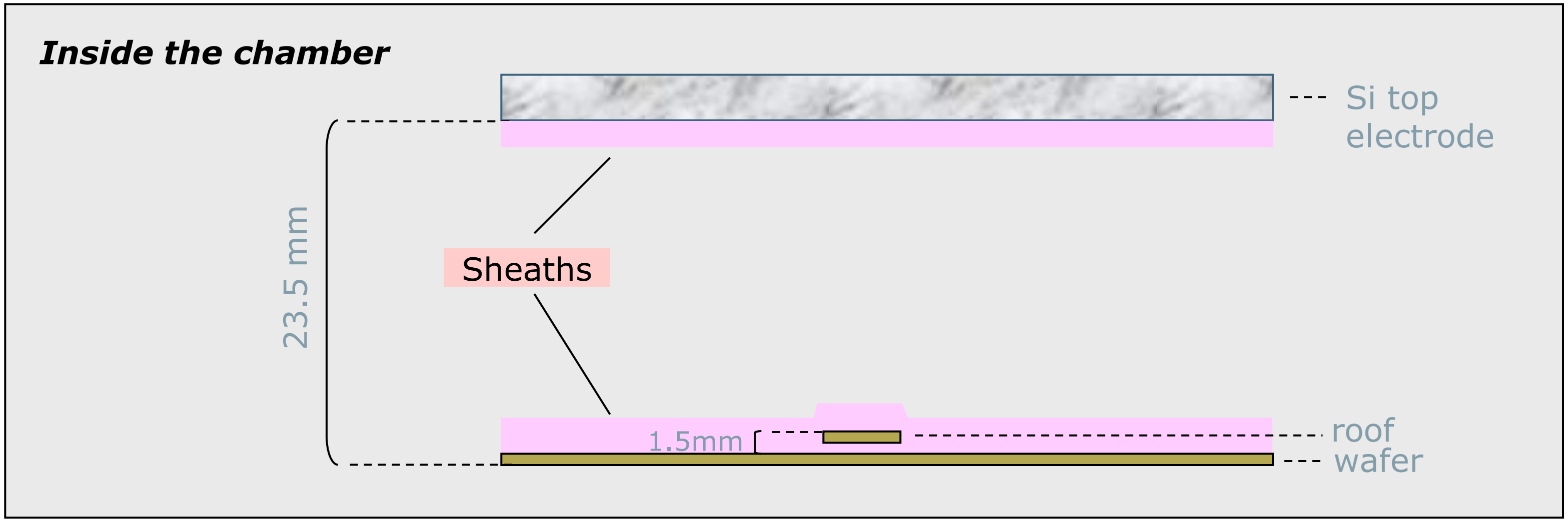




- Profile control is driven by sidewall polymers
- There is a need for a better way of characterizing those polymers
  - In such structure even XSEM is marginal
  - No ellipsometry can access sidewalls
  - Scatterometry is an option, but morpho & heavy to implement
  - AR-XPS is heavy & time-consuming
- Alternative approach: simulate sidewall geometry with a roof structure
- Constraints
  - Need to be compatible with hardware, total height < 3mm
  - Roof material need to be compatible also

Experimental setup





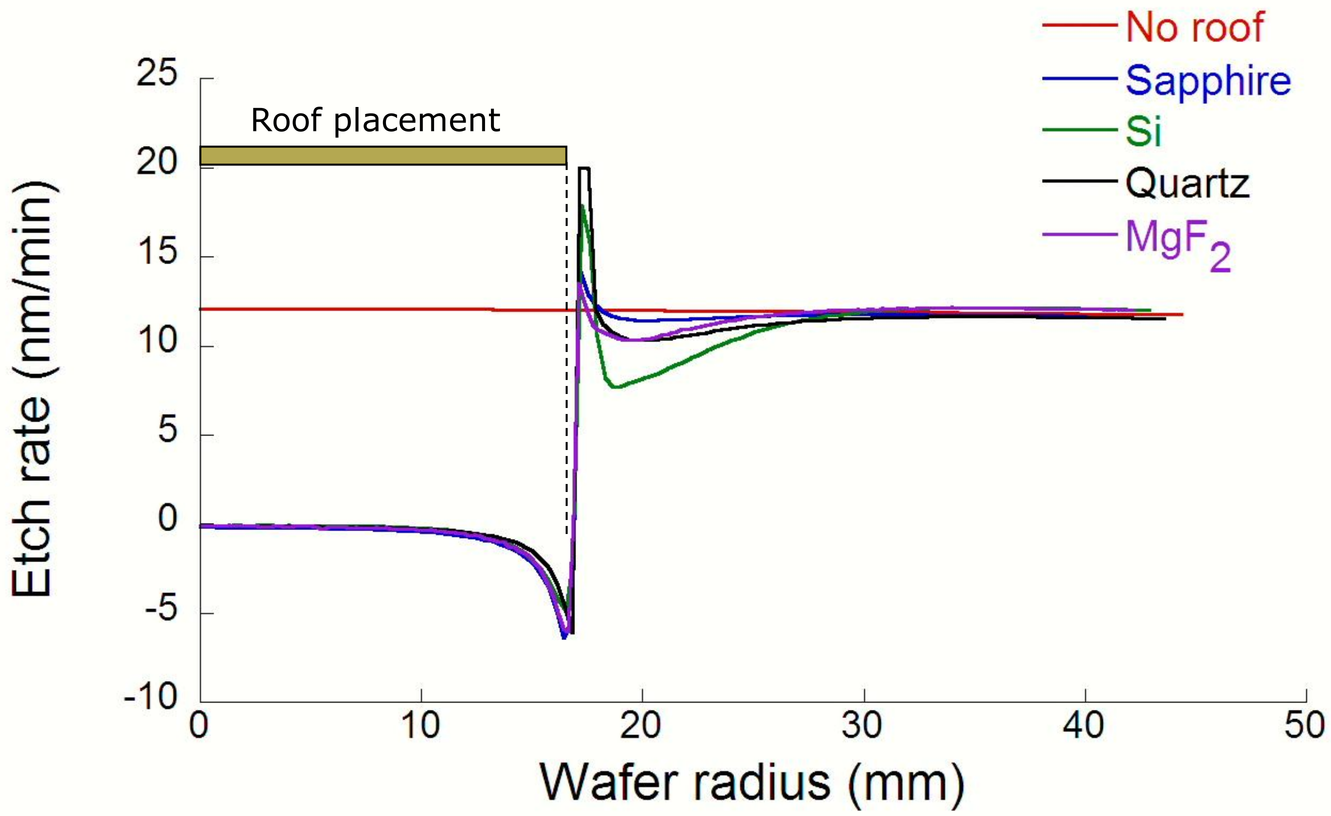
Questions to be answered / tools

- What is the influence of the roof structure on the *local* plasma physics and chemistry?
  - Nature of the roof? Which material suits best?
  - How does it depend on the plasma used?
- Which part of the roof structure is going to give us a best model of the sidewall polymers?
- Can it be used to simulate sidewall polymers appearing with the TiN MHM approach?

- Chambers:
  - 2300 Exelan Flex / Flex45 (300mm) (etch tests)
  - 2300 μw stripper (ash tests)
- Ellipsometry measurements, F5-SCD (Kla-Tencor)
- PlasmaVolt (Kla-Tencor SensArray)
- XPS analysis

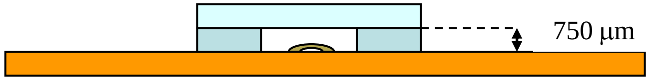
Influence of the roof

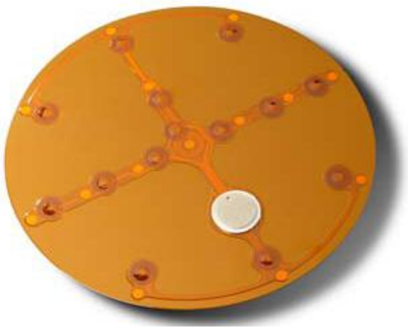
- 20 mT / 300 sccm Ar / 500W 27MHz
- SiO_2 etch rate

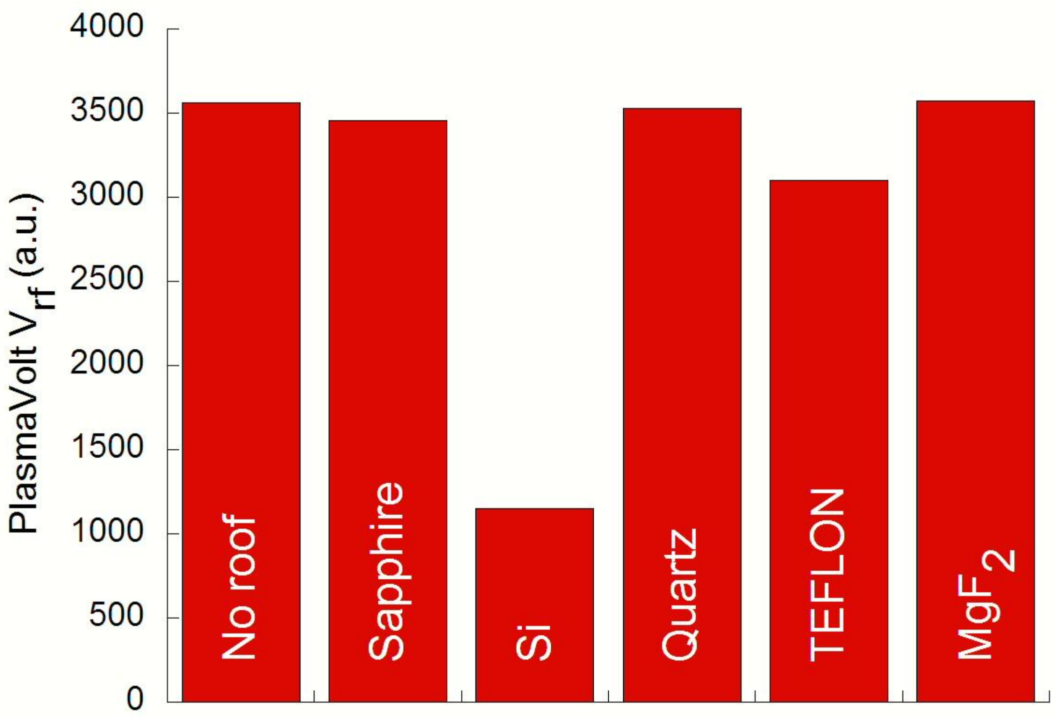


PlasmaVolt® Measurements

- 20 mT / 300 sccm Ar / 500W 27MHz
- PlasmaVolt® sensor covered by roof
- Voltage $V_{rf} \sim I_{rf}$ between wafer and plasma*



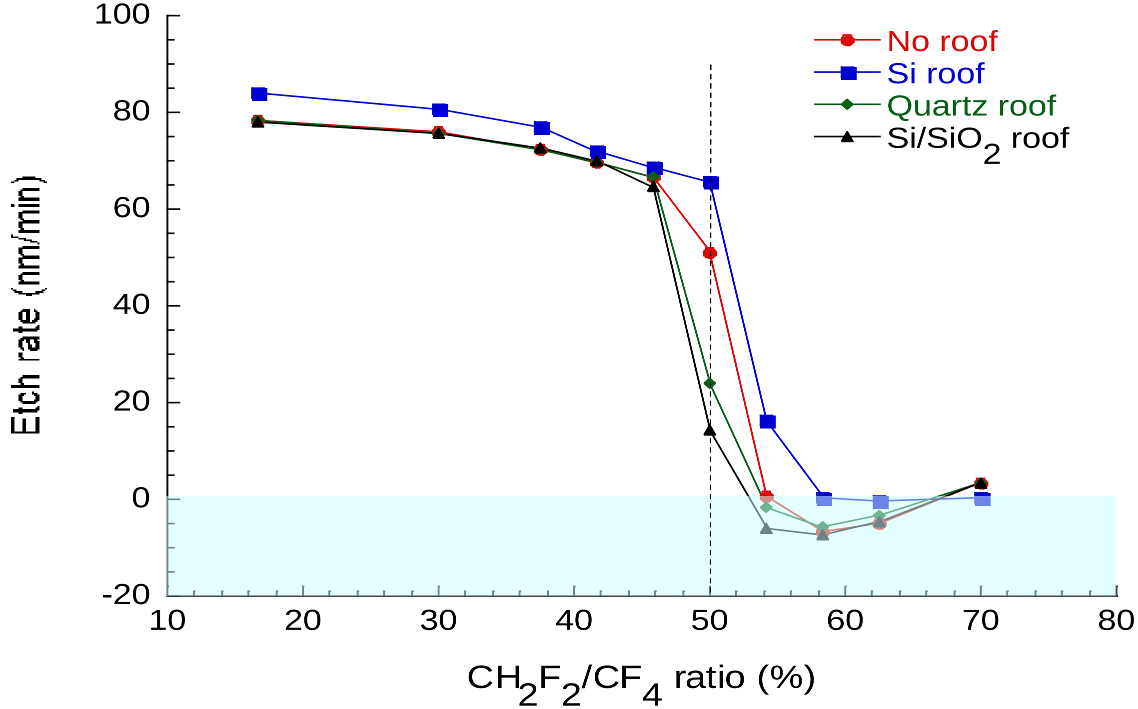




* M.J. Titus et al, J. Vac. Sci. Technol. A 28(1), 139, Jan/Feb 2010

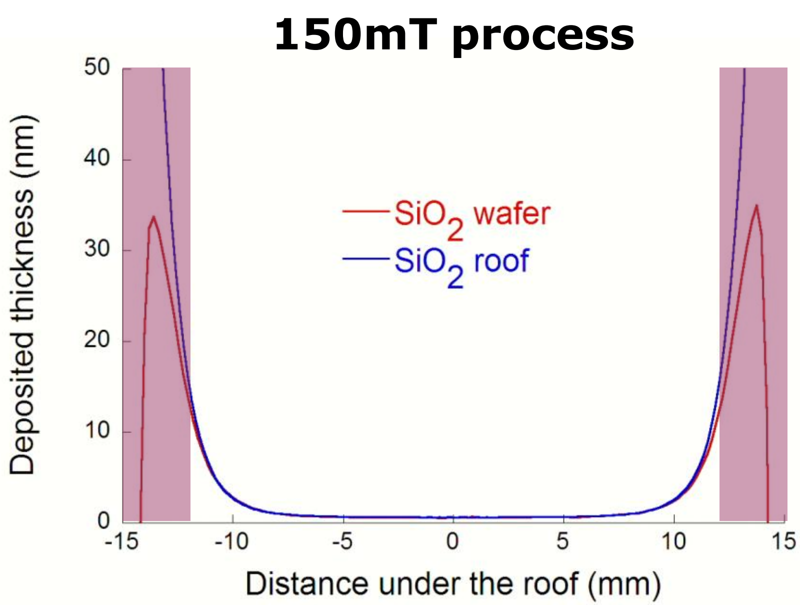
Effect of Si roof in polymerizing plasma

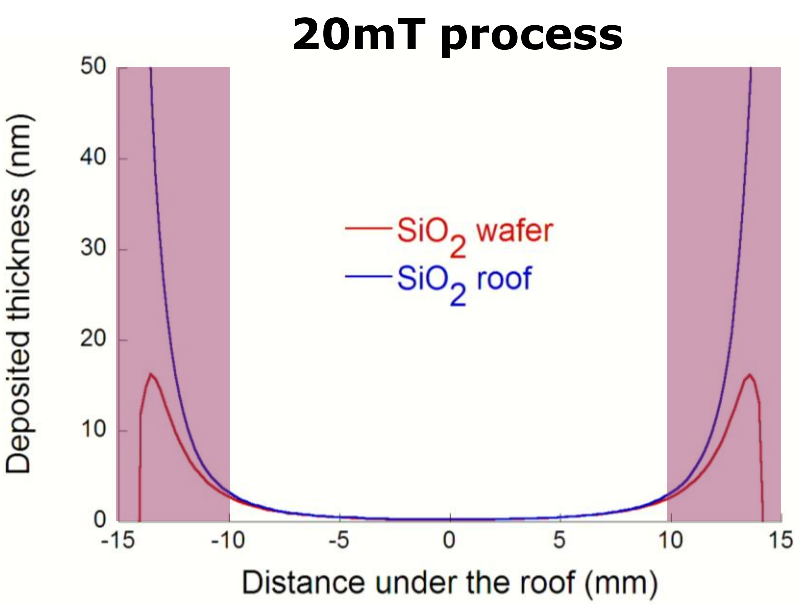
- Effect of placing a roof in the middle of the wafer
- Check average ER over full wafer except central area
- 20 mT / 300scm Ar / 500W 27MHz / 60 sccm CH_2F_2+CF_4
- SiO_2 etch rate



Ion deflection issue

- Ions can still be deflected under the roof (sheath deformation / mean free path)
- Use the inverted gap approach: compare what is being deposited on the roof and what is deposited on the wafer
- 20 or 150mT / 300 sccm Ar / 500W 27 MHz
- SiO_2 etch rate

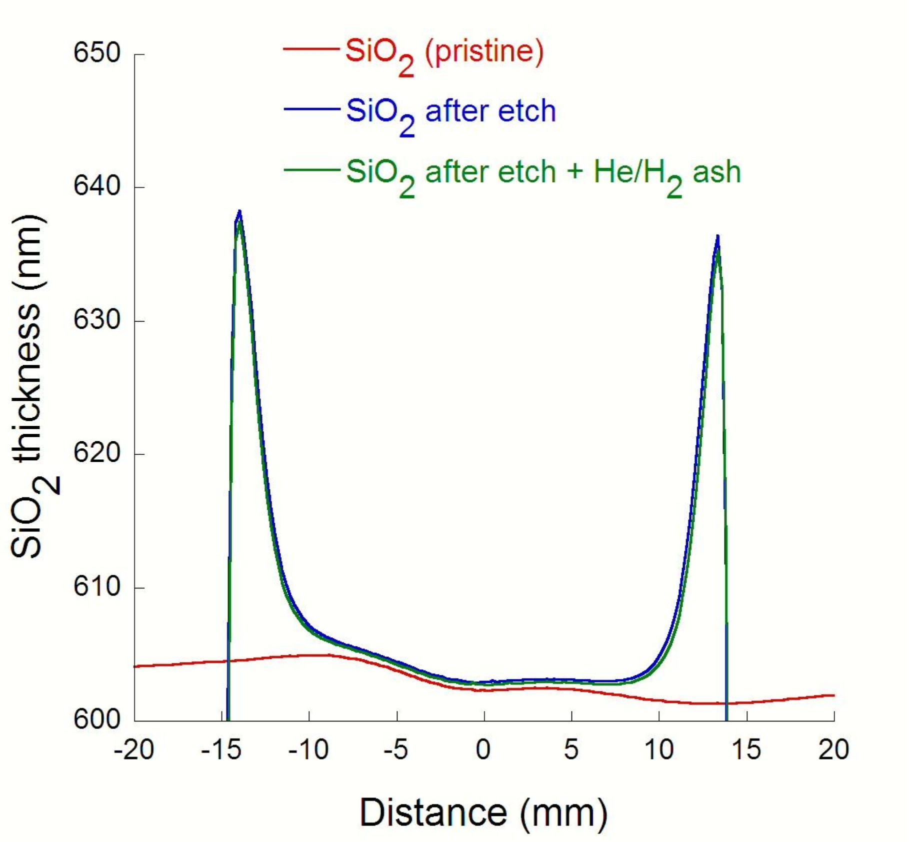


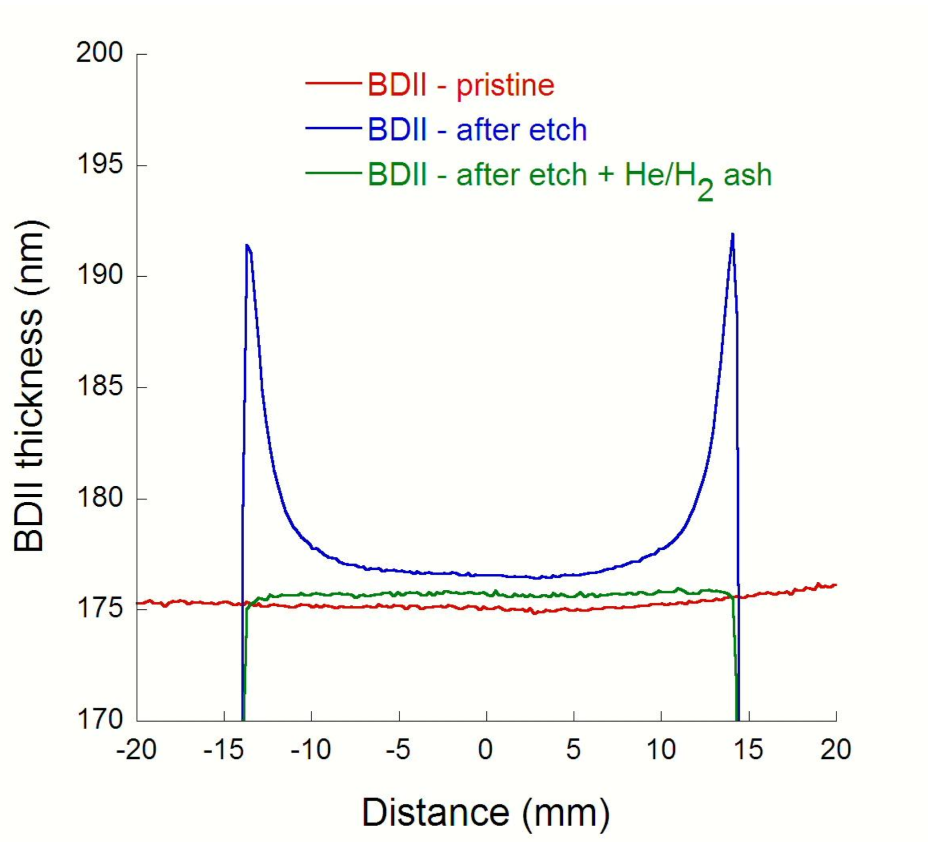


What deposits under the roof?

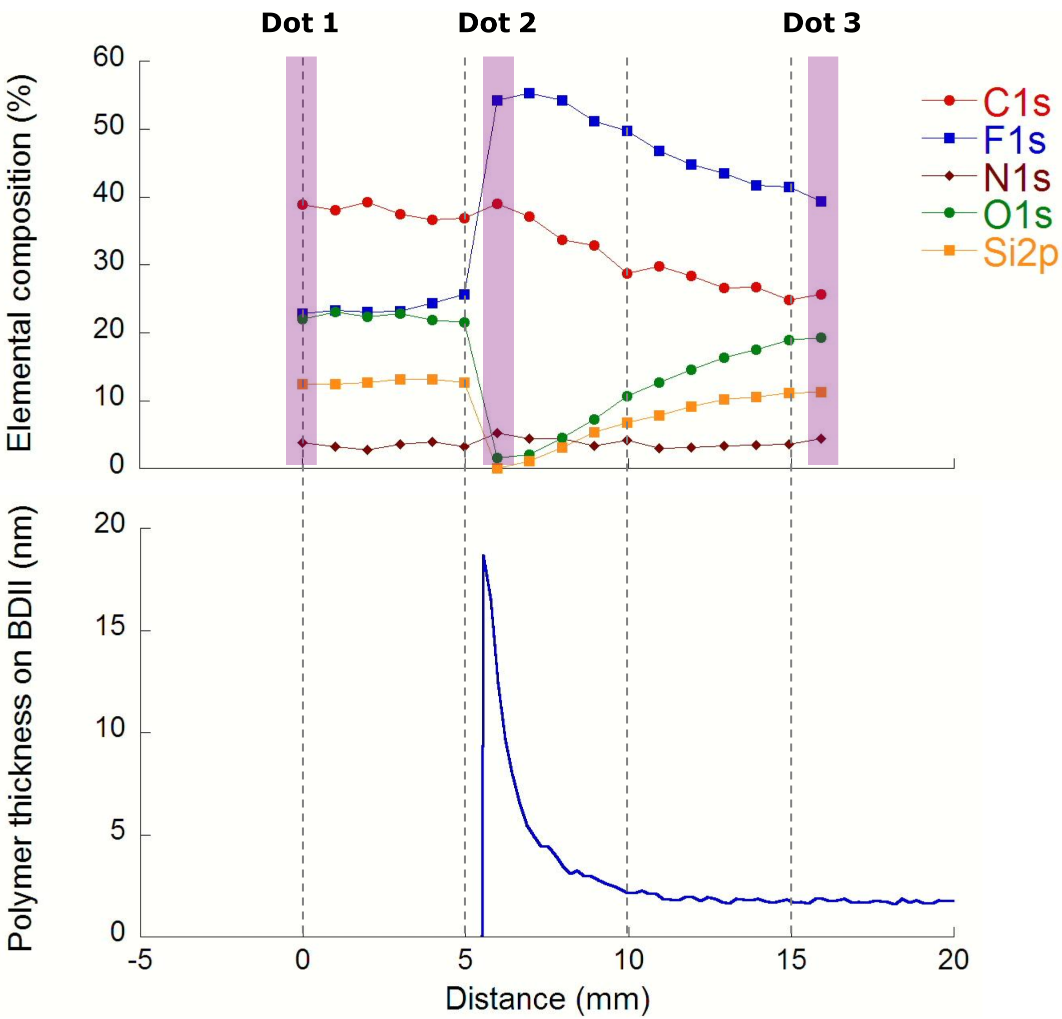
Pure Ar discharge on SiO_2

C_xF_y-based discharge on BDII

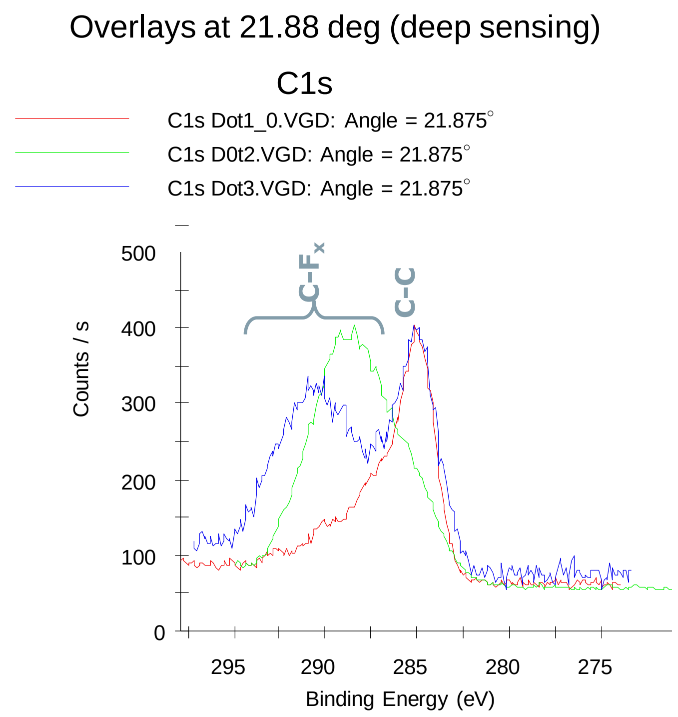




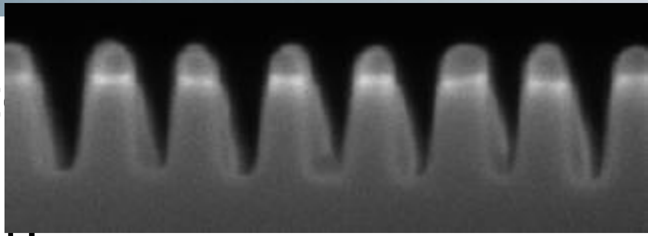
Analysis of deposits



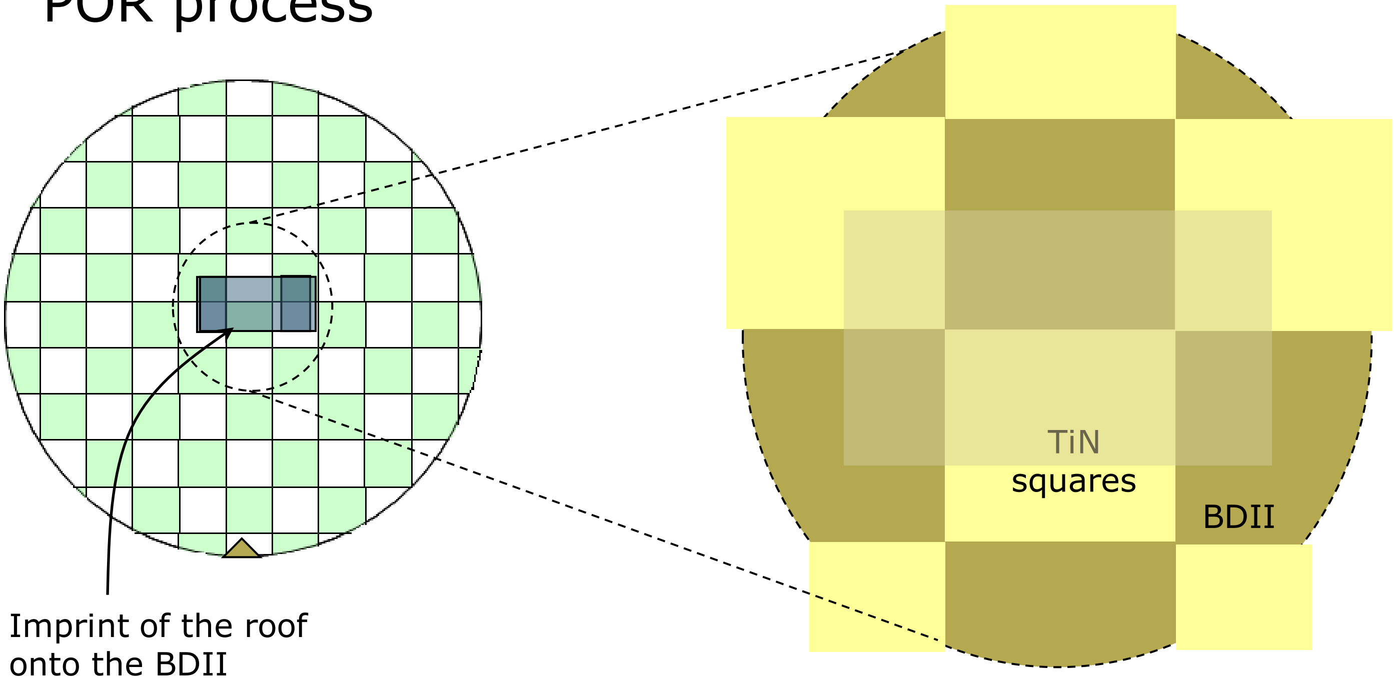
C_xF_y-based discharge on BDII



MHM simulation: introduce TiN



- Simulation of MHM-based BDII trench etch
- Use a TiN/BDII checkerboard pattern
- Quartz roof for reduced plasma perturbation
- Use the inverted gap approach: compare what is being deposited on the roof and what is deposited on the wafer
- POR process



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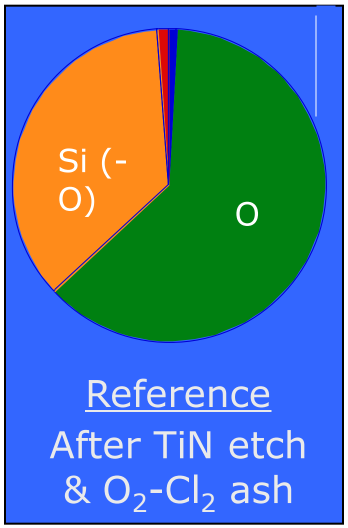
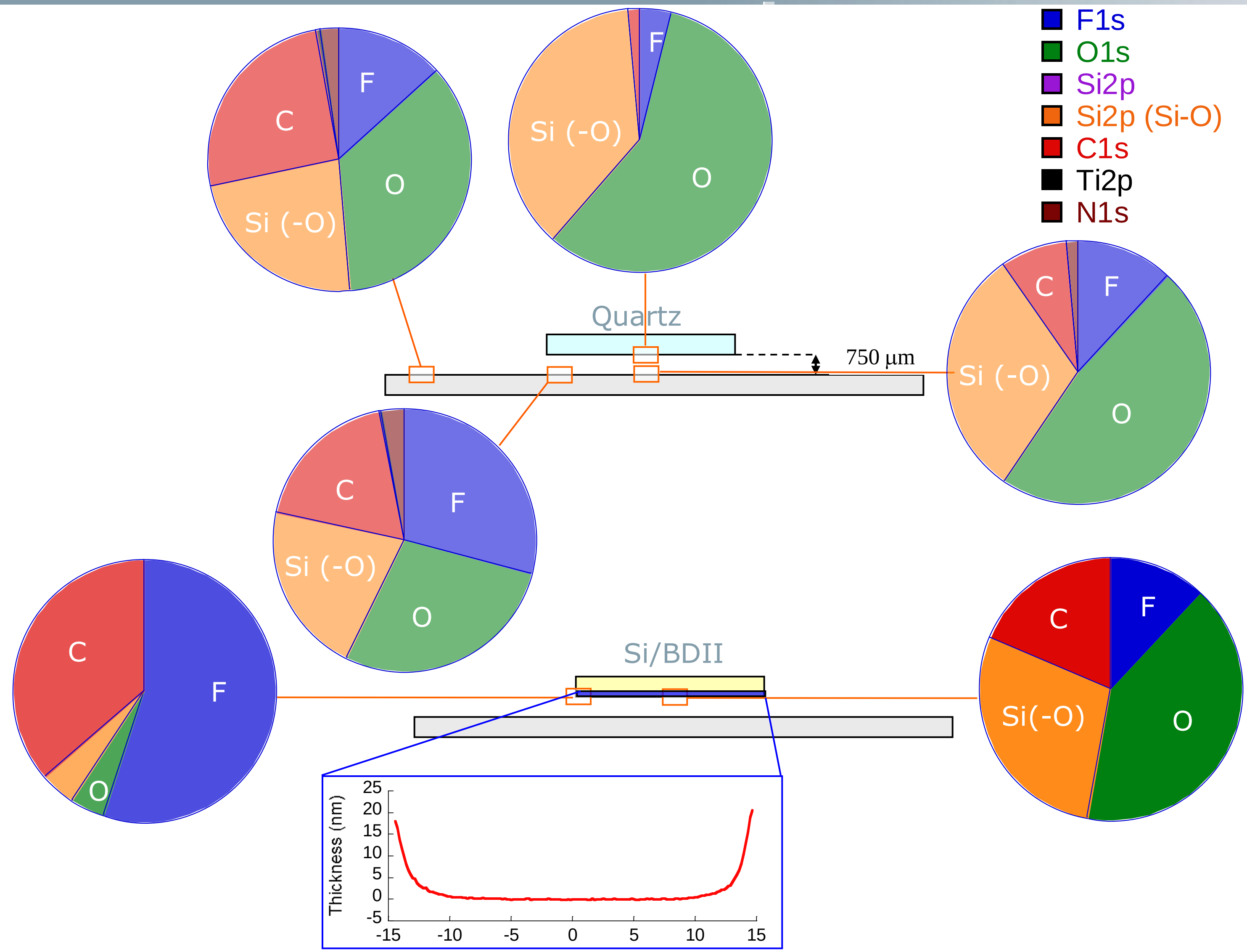




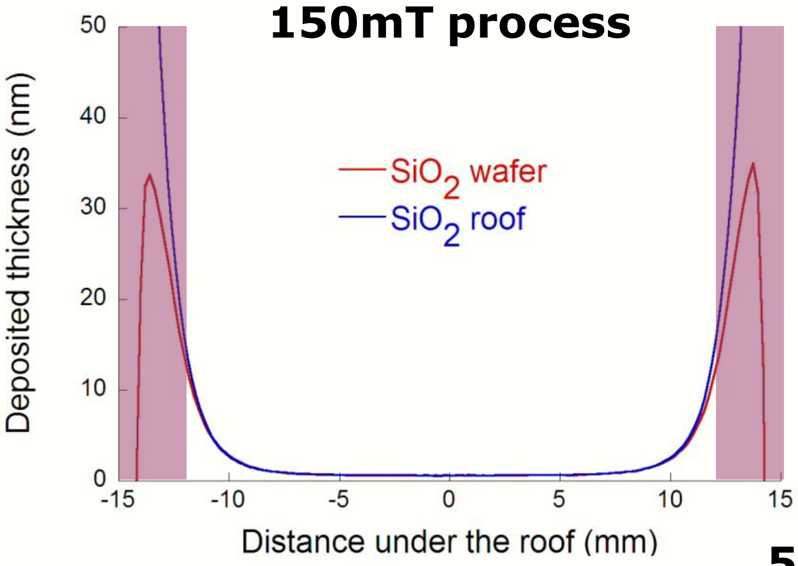
Conclusion

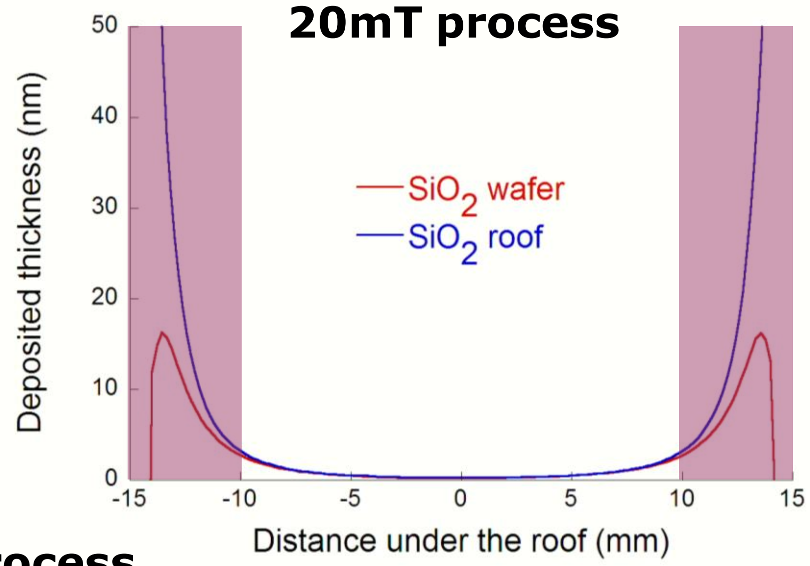
- The small-gap technique has been investigated
- The nature of the roof is important: MgF_2, quartz or Al_2O_3 are advised for not perturbing the plasma too much, Si is not the best material. However, for practical reasons, Si remains very flexible (we can deposit layers on it).
- In order to avoid perturbation by ion sputtering, it is advised to look at the backside of the roof i.o. the wafer itself. In case we can't avoid using the wafer, we have to take care of inspecting a region under the roof which is free of ion sputtering.
- In fluorocarbon discharges, polymers deposit at the edges of the roof
- A straightforward comparison of the polymer deposited in a real trench and under the roof is needed so as to validate the technique.

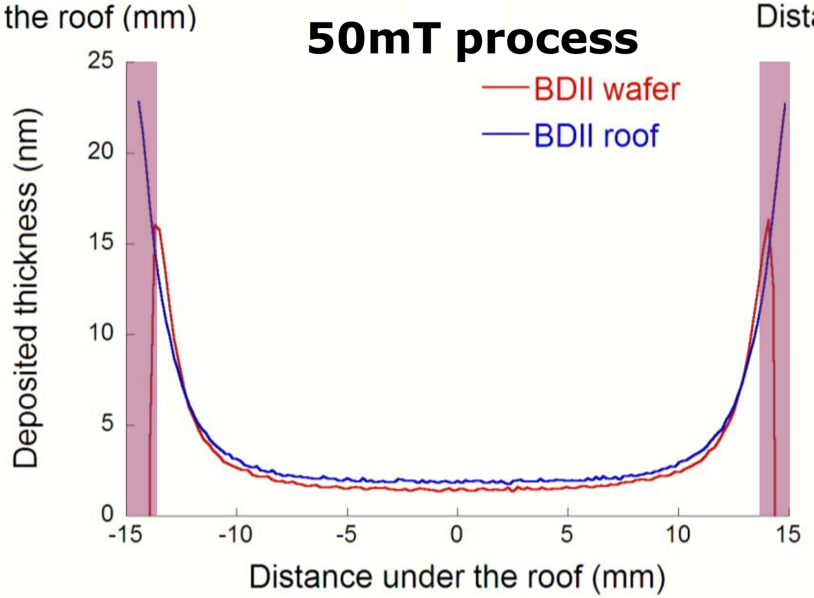
Interests of the technique

- Sidewall simulation
  - Polymer formation for post-exposure treatment studies
  - Polymer formation for cleaning test studies
  - Study of dependence of polymerizing nature of plasma on discharge parameters
- Effect of neutral/light interaction with substrate
  - Photoresist degradation / LER-LWR studies

Ion deflection issue







Parameters for the IED in a RF discharge

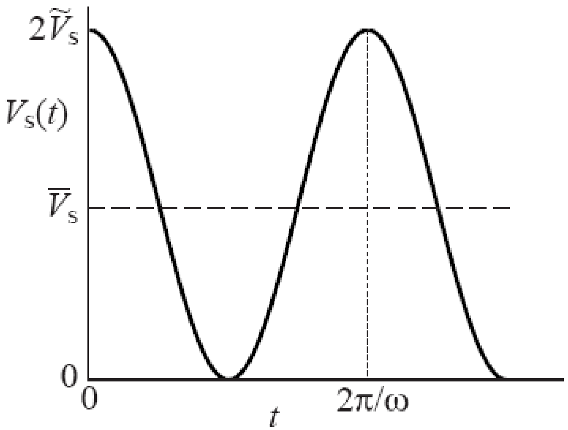
- Pressure P or mean free path $\lambda_i(mm) = \dfrac{30}{p(mT)}$ (Lieberman)

$$\lambda_i(mm) = \frac{50}{p(mT)} \text{ (Coburn)}$$

- Driving frequency ω
- Sheath voltage

$$V_s(t) = \tilde{V}_s(1 + \cos\omega t)$$

- Average sheath voltage $\bar{V}_s =$ rf amplitude $\tilde{V}_s$
- Sheath thickness l_{sh}
- Ion transit time τ_i in the sheath



Type of discharge in a Lam Research Flex

typical data[1] for Ar plasma in a CCP at 13.56 MHz:

Collisional RF sheath

Collisionless limit

P (mT)	l_{sh} (mm)	λ (mm)
10	10	5
50	5	1
500	4	0.1

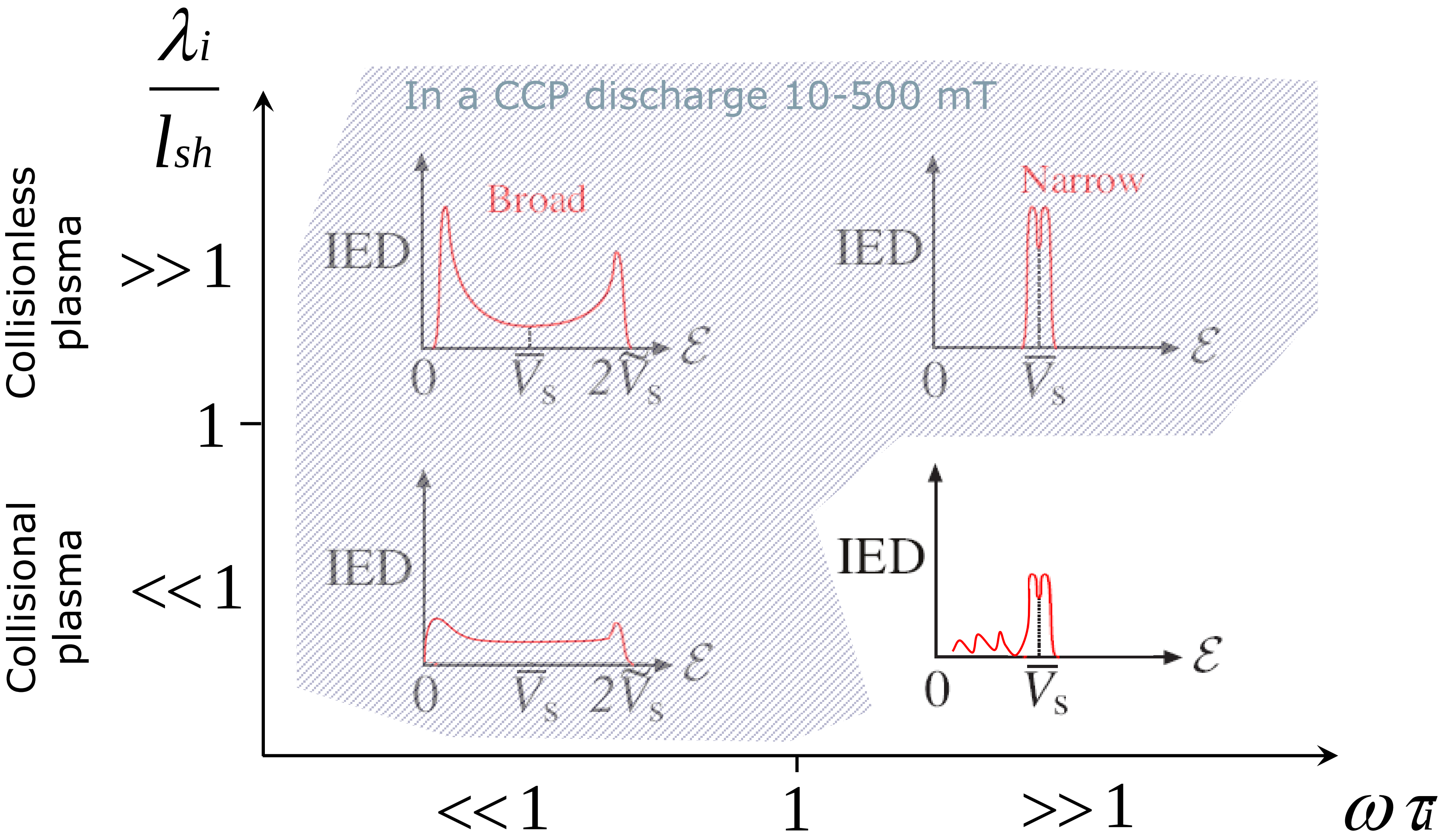
- Allowed P range: 20-600mT, $0.05-0.08<\lambda_i(mm)<1.5-2.5$
- Observed sheaths thickness l_{sh} vary from ~ 10 to 1mm

$\rightarrow$ In most cases, we see a *collisional sheath*, except at *low pressure* where it is almost *collisionless*

- Typical $\overline{V}_s \approx 150V$ for a CCP discharge (however may vary from 100 to >1000V)
- Quick calculation indicate $v_i = 2.7*10^4 m/s$ for Ar ion
- $10^{-6} < \tau_i < 10^{-7} s$ for a 1-10mm sheath thickness
- To be compared to $27MHz \Leftrightarrow 3.7*10^{-8} s$

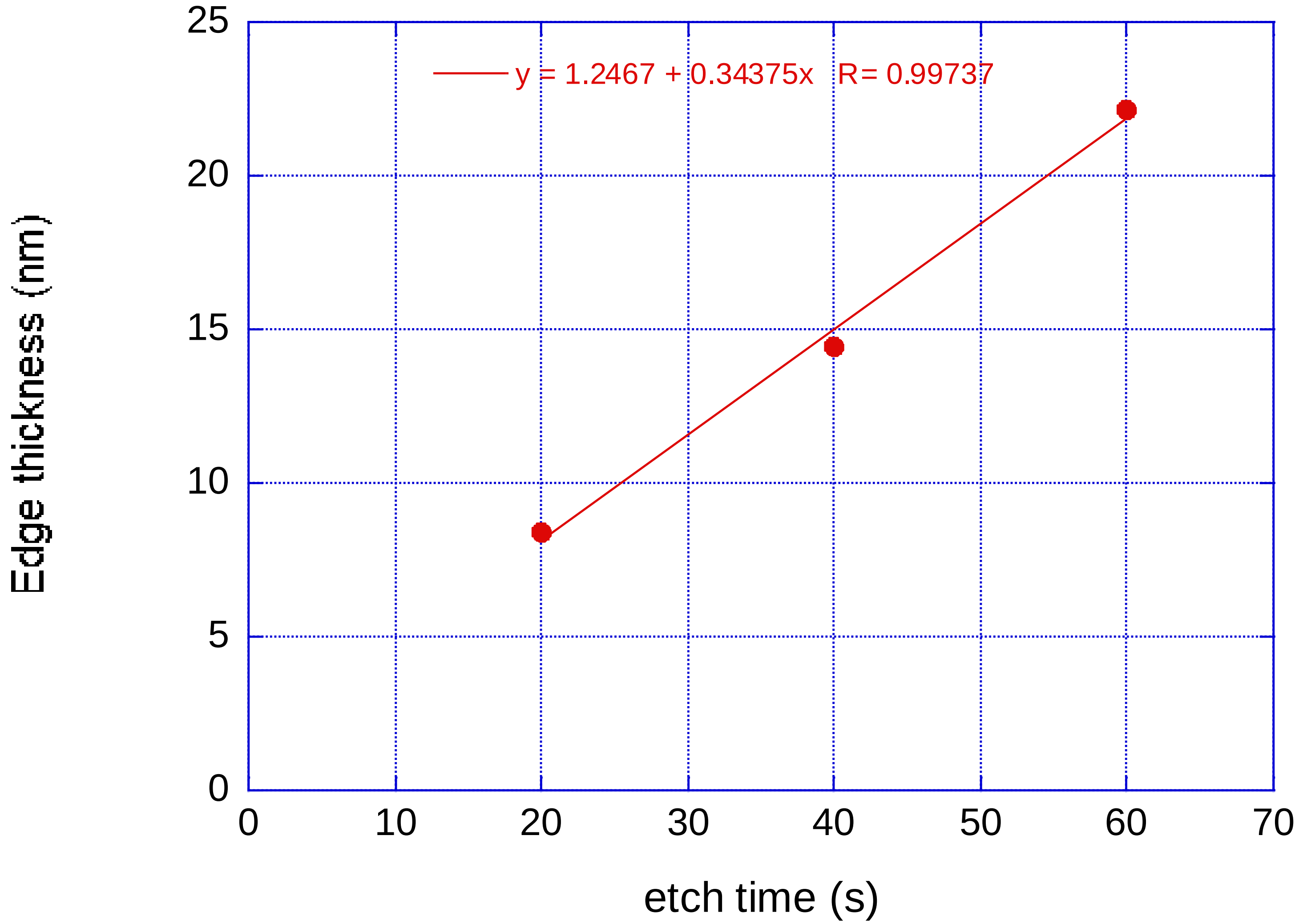
$\rightarrow$ In most cases, we are in the $\omega\tau_i >> 1$ limit

IED in an Exelan Flex



AE090840 D13-15

Linearity of polymer deposition



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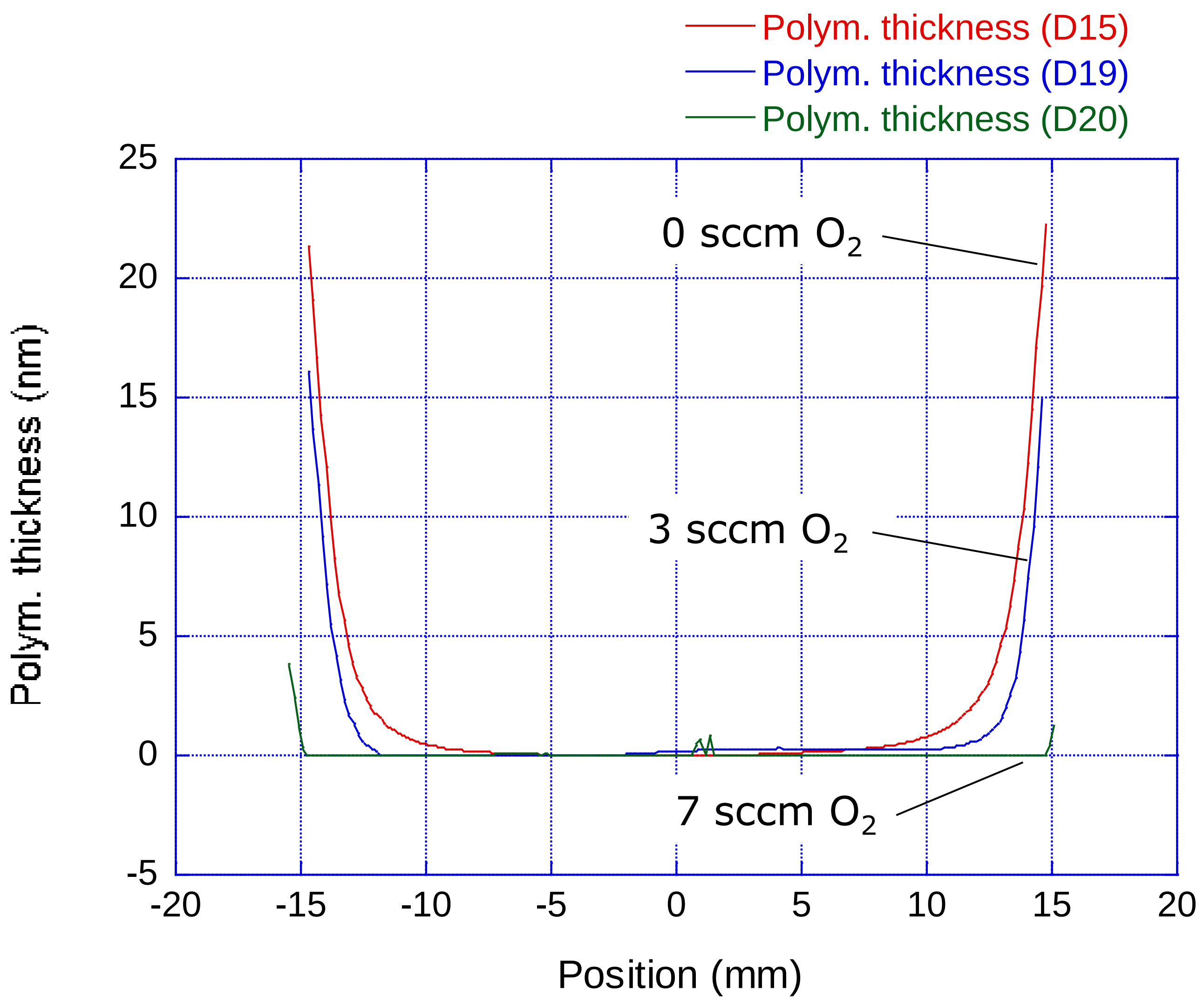
Effect of O_2 addition



25 imec

Years of Making Technology Fly